Ways to Reduce Arc Flash Energy

When short circuits occur on an electrical distribution system, an arc flash event usually forms. These arc flash events can cause dangerous and potentially fatal levels of blast pressure, excessive sound waves, toxic gases, vapors, heat, ultraviolet radiation, and flying shrapnel. Arc flash produces thermal, radiation, chemical, mechanical, and electrical energy.

The electrical industry, International Electrical Electronic Engineers (IEEE), National Fire Protection Association (NFPA), and Occupational Safety and Health Administration (OSHA) are now aware of the hazards. NFPA 70E and IEEE 1584 standards mainly deal with the heat energy from the arc flash. This energy produced by an arc flash event is proportional to voltage, current, and the duration of the event (Volts $\propto$ Current $\propto$ Time) with the duration time affecting the energy levels the most.

OSHA is now enforcing NFPA 70E and is requiring employees to be protected from electrical hazards. NFPA 70E requires that an Arc Flash Hazard assessment or study be performed to determine the Arc Flash Incidental Energy, Flash Boundary, and Hazard Risk Category. From this Hazard Risk Category, the proper Personal Protective Equipment (PPE) can be determined to protect personnel when servicing energized equipment. The National Electric Code (NEC) 2017 also has a section requiring Arc Flash Warning Labels on equipment in non dwelling facilities.

Section 110.16 Arc-Flash Hazard Warning - *Electrical equipment, such as switchboards, switchgear, panelboards, industrial control panels, meter socket enclosures, and motor control centers, that is in other than dwelling units, and is likely to require examination, adjustment, servicing, or maintenance while energized, shall be field or factory marked to warn qualified persons of potential electric arc flash hazards. The marking shall meet the requirements in 110.21(B) and shall be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment.*

Determining the proper PPE to reduce injuries and burns from arc flash is the goal of an Arc Flash Hazard assessment (arc flash energy calculation). Many facilities have locations where the arc flash energy levels are extremely high. These dangerous areas require electricians and technicians to wear heavy PPE for protection. In some areas and locations, this PPE can increase the chances of heat stroke and other heat related problems.

This paper will discuss how arc flash energy is calculated and what affects the calculations. There are several design, retrofit methods, and procedures that will reduce the arc flash energy. This includes the use of fuses, relays, and circuit breakers. Lowering the arc flash energy will decrease equipment damage and increase equipment and personnel protection.

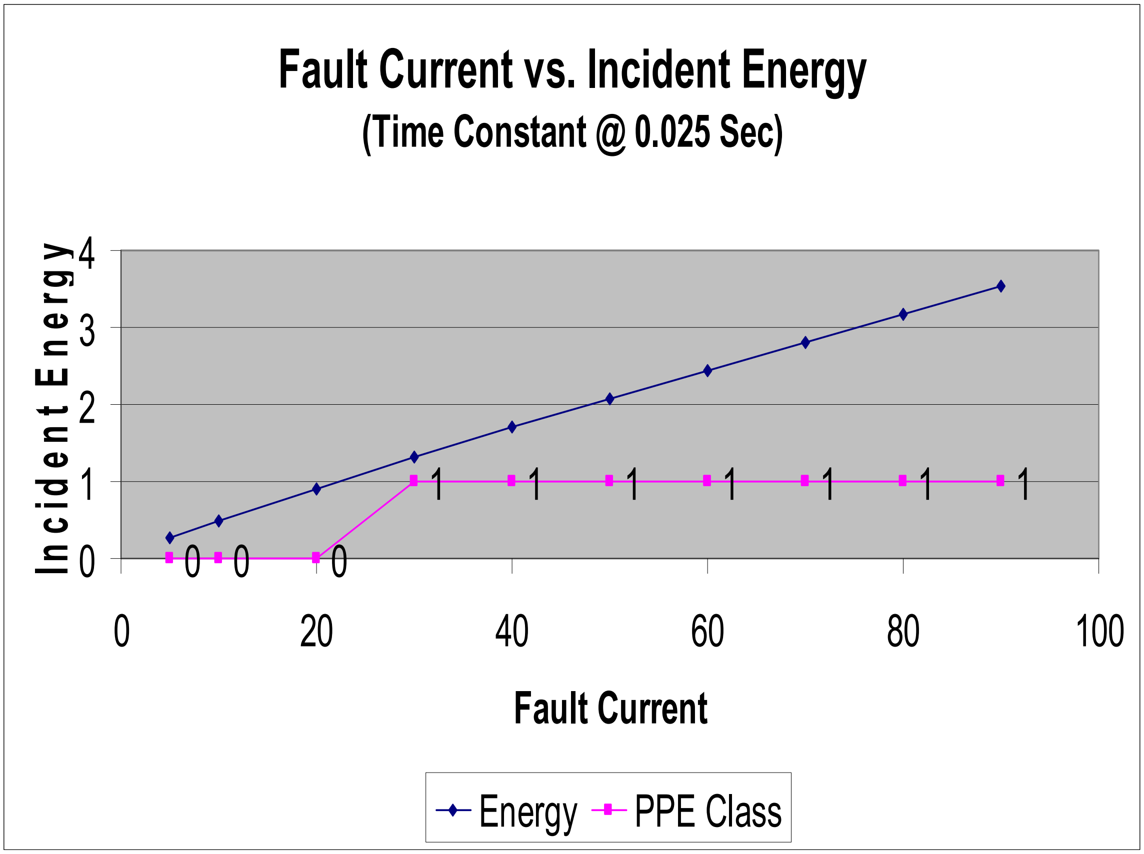
Design engineers have a few options to reduce system voltage or fault currents. But, the best and most direct ways to reduce arc flash hazards are to reduce fault-clearing times.

Arc flash energy can be estimated or calculated by using NFPA 70E* Tables, IEEE 1584 equations, Arc Pro, or Lee Equations. These methods determine the arc flash hazard incident energy levels and arc flash boundary. Once the energy level is determined, then the appropriate PPE can be determined by Tables 130.5(G) & *130.7(C)(15)(c).

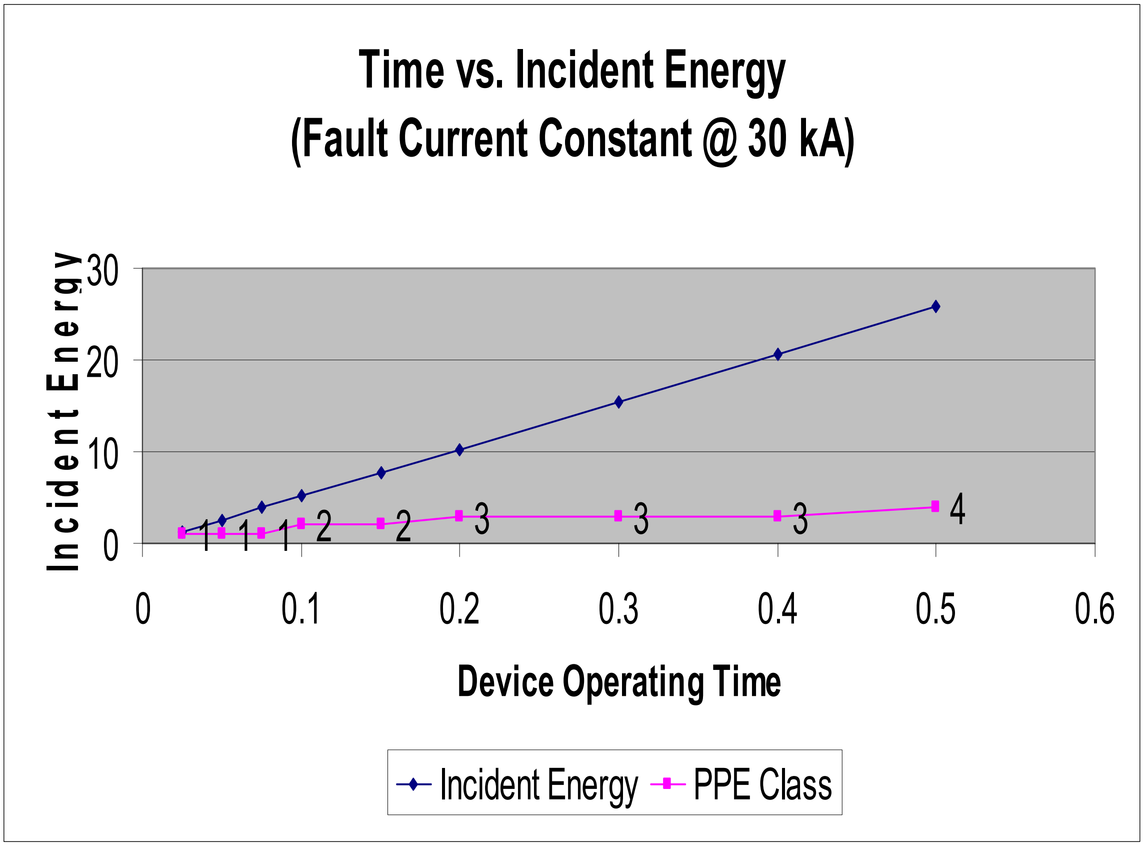
For this article we will focus on what affects the energy calculations and what a design or facilities engineer can do to reduce arc flash energy. We will use the IEEE 1584 equations to calculate the energy levels. The Arc Flash Energy Equations in IEEE 1584 require many variables that include equipment bolted fault currents, arcing fault current, and the upstream protective device clearing times. The calculations are also dependent upon operating voltage, gap length, enclosure type, enclosure size, and electrode configuration. These items are very difficult to change in an existing facility. The greatest effect on the calculations is time the upstream device operates, followed by working distance, and then available fault current.

The three graphs below show just how much time can affect the energy calculations. For graphs 1 and 2, the working distance is held constant at 18 inches. Only in the last graph is the working distance varied. Each graph shows the Arc Flash Energy on the vertical axis and is a blue line. The pink line shows the NFPA 70E Hazard Category.

Graph 1 below shows the effect of raising the fault current when the device operating time is held constant at 0.025 seconds. This is the typical clearing time of a molded case circuit breaker tripping instantaneously. As the fault current is raised from 5,000 amperes to 90,000 amperes. The graph shows that if the device is tripping quickly, raising the fault current does not significantly affect the NFPA 70E Hazard Category. The energy levels rise slightly.



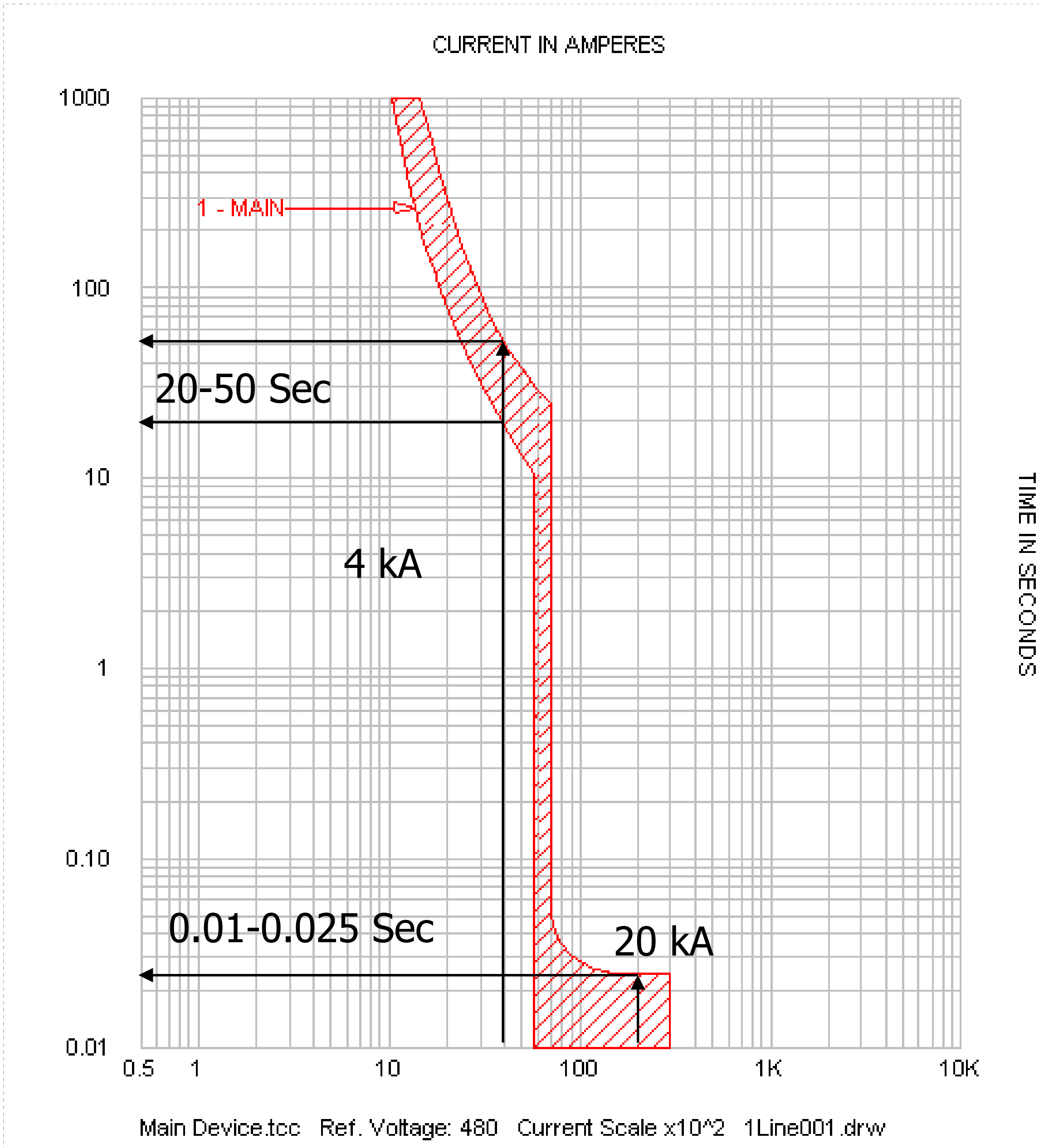
Graph 1 – Fault Current vs. Incident Energy Level



Graph 2 – Device Operating Time vs. Incident Energy Level

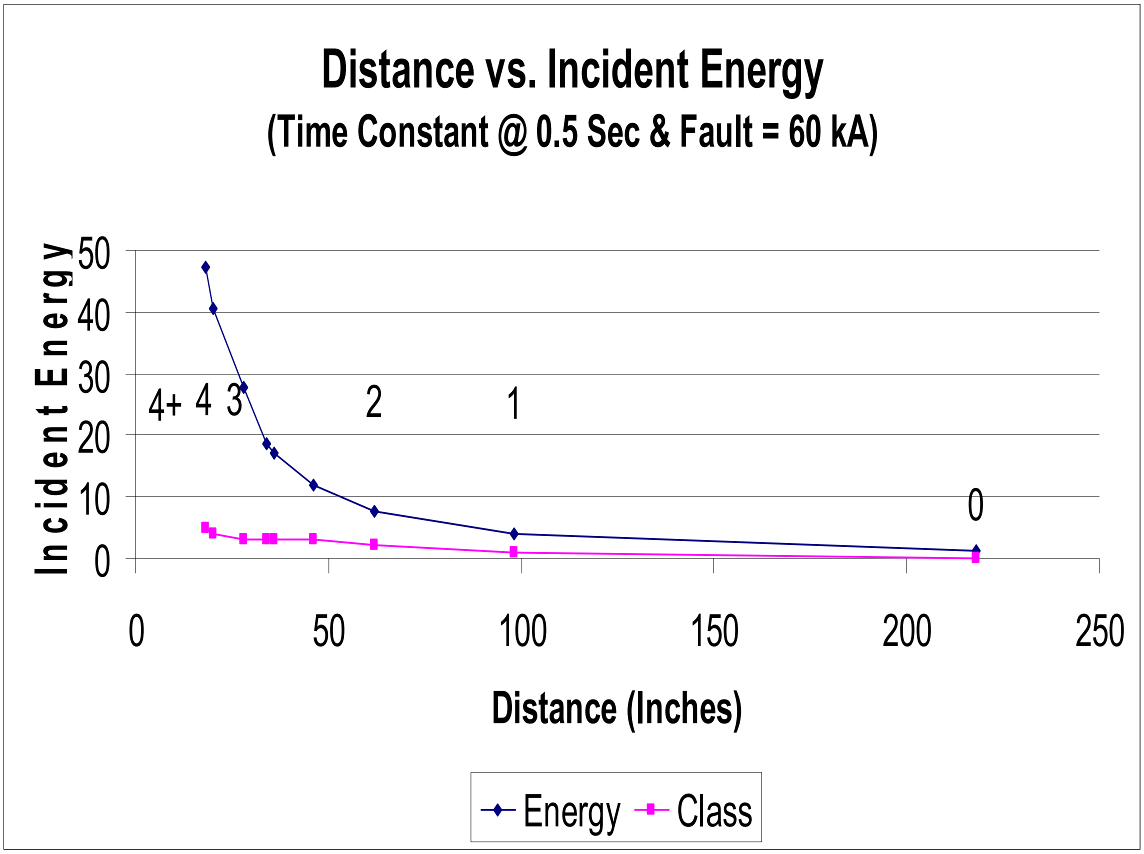
Graph 2 above shows the effect of changing the device operating times from 0.025 seconds to 0.5 seconds (0.5 seconds is the longest short time delay setting available for breakers with solid state trip units.) For these calculations, the fault current is held constant at 30,000 amperes. This graph clearly demonstrates that the device operating time has a huge impact on the calculations.

It should be noted that in the real world, changing fault currents can affect the upstream device operating time. If the fault current is reduced below the breaker's instantaneous setting or fuse current limiting threshold, then longer delay times can be expected. Usually, the net effect of a lower fault current and longer device operating time is a higher energy level. This occurs quite often when equipment downstream of an automatic transfer switch (ATS) is fed by a generator and normal utility source. The energy levels of this downstream equipment can be higher when on generator power than when fed by utility power. This is because the upstream protective device operates slower due to the generators reduced fault current. The time current curve below (Graph 3) shows how the reduced fault current can affect the way the protective device operates. This demonstrates the importance of performing the energy calculations and why it is important to know sources and levels of fault current.



Graph 3 – Thermal Magnetic Trip Circuit Breaker Time Current Curve

Graph 4 below is a plot of personnel working distance versus energy. The fault current and device operating time are held constant while the working distance is raised from 18 inches to 225 inches. This graph shows that the energy is reduced by increasing the distance between the worker and the fault location.



Graph 4 – Working Distance vs. Incident Energy Level

Reducing the fault current can have an effect on the energy calculations but it is extremely hard to reduce at an existing facility. It is usually done during the design phase of a new facility. Several ways to reduce this fault current are the use of several smaller transformers and unit substations versus one large one. This also increases the system reliability by having several substations feeding equipment instead of one. Installing tie breakers will further increase the reliability should one of the substation services fail. (The bus tie breakers must not be closed unless one of the main breakers is open.)

Another method of reducing the fault current is the use of Current Limiting Reactors or transformers. These devices have been used in many facilities to reduce the fault current to levels below the equipment short circuit ratings. Although this is a costly method, there may be other reasons for implementing this option.

The best way to reduce arc flash energy is to clear the arcing fault as quickly as possible without sacrificing coordination. Current limiting fuses operate extremely fast (if operated in the current limiting range). They reduce arcing current and energy levels. They are simple to install and have very little maintenance requirements. However, if the line side is energized, the electrician will need to wear appropriate PPE (based upon the line side energy calculations) to install a fuse that has blown.

The energy levels can be reduced further by replacing older non-current limiting fuses with modern fast operating fuses with faster clearing times. Even replacing expulsion type fuses with current limiting fuses have been shown to be beneficial. Another simple method is to reduce the fuse ampere size. Many circuits in a distribution system are under utililized. If a 400 ampere fuse is feeding loads that draw only 200 amperes, then the 400 ampere fuse can be reduced which will increase the chances that the fuse will operate in the current limiting region for an arcing fault. However, it is important to check the inrush current of motors and transformers and verify that the fuse will not be damaged when these devices are energized.

When using circuit breakers, there are many options available to reduce the arc flash energy. Using simple current limiting breakers that will operate in the instantaneous region and current limiting region will reduce the energy levels. Also, using breakers with solid state trip units that have adjustable long, short, and instantaneous settings is an effective method for reducing arc flash energy. Most new solid state trip units can be ordered with an additional Arc Flash Energy Reduction (AFRM) function. This function can be turned on and off as needed to protect electricians when working downstream from the breaker.

The curve below shows the adjustable trip functions for a breaker with a solid state trip unit. This is achieved by setting the short time pickup and delay as short as possible but to coordinate with the largest downstream load. This insures that the breaker will still trip quickly if the arcing fault current falls below the breaker instantaneous setting.

As previously discussed, device operating time has a great effect upon the energy levels. Therefore, reducing the trip times to as low as possible without sacrificing selective coordination is very important. For double ended unit substations or switchboards, it is important to reduce the main settings to coordinate with the largest feeder breaker not with the tie breaker. This is because the tie breaker is rarely used and is there only for emergency or maintenance conditions.

Another way to reduce the arc flash energy at locations where solid state trip units are being used is to order the trip units with the Zone Interlocking feature. This feature adds communication between the main, tie, and feeder breakers. If a fault occurs downstream from the feeder breaker, a “restraint” signal is sent to the main and tie breakers to time out using their normal programmed LSI trip settings. If a fault occurs between the main and feeder breakers, “no restraint” signal is sent to the main and bus tie breakers. They will then trip at a very low pickup and time delay.

Another similar method is to employ differential protection. Zones of protection are set up using differential relays and current transformers. If a fault occurs within the zone, the relay trips at extremely low pickups and time delays. This again greatly reduces the arc flash energy. Some manufacturers are now offering this option on low-voltage switchgear using breakers with solid state trip units.

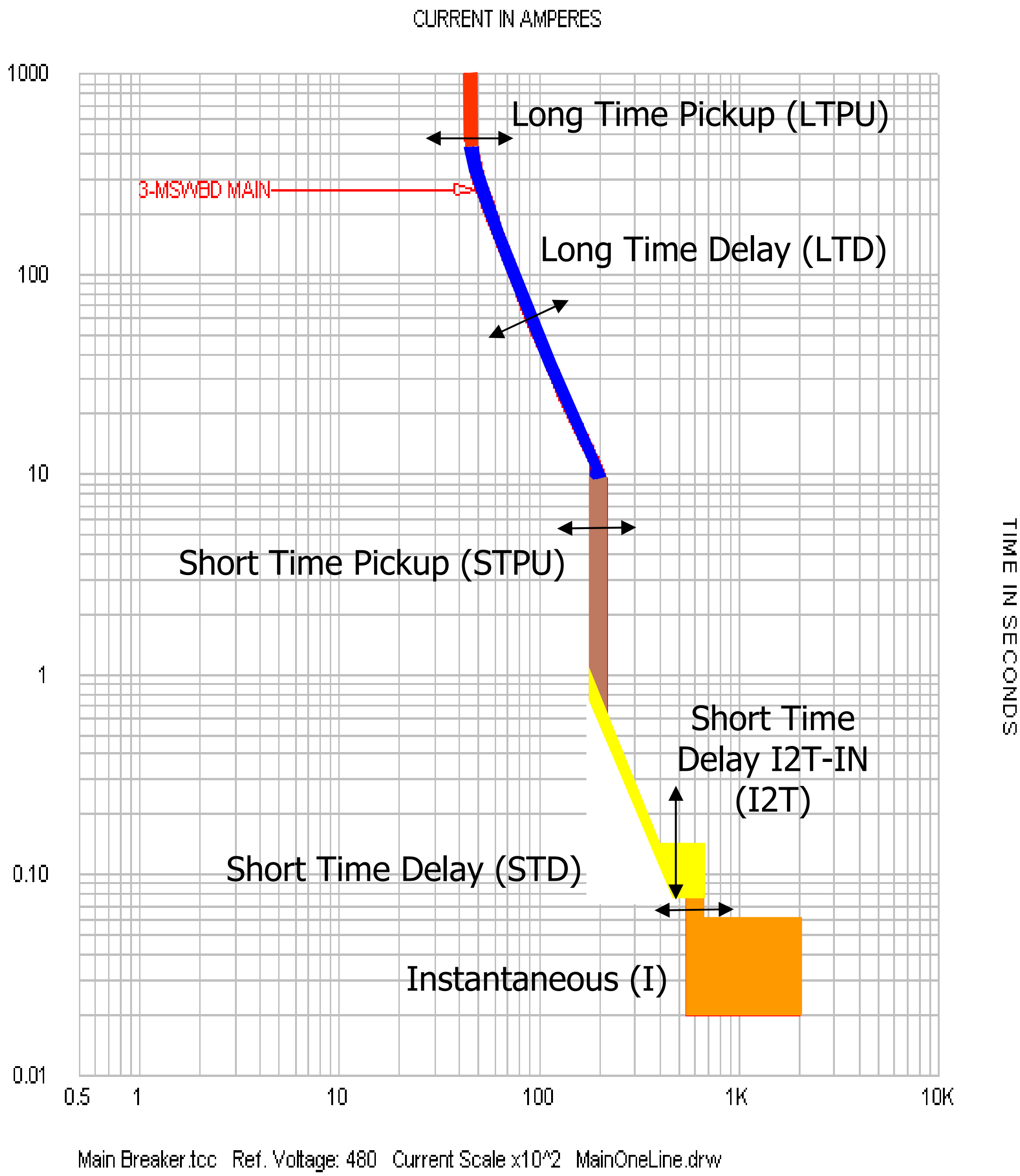
For breakers that have the AFRM functions enabled and greatly reduce the arc flash energy downstream. The AFRM function has a low pickup setting with no time delay.

In short, the breaker trip unit converted from a LSI trip unit to an I (Instantaneous) only unit. When breaker trip quickly, the arc flash energy is reduced.

Photo 5 – Arc Flash Reduction Mode on Trip Unit

Some switchgear manufacturers have employed arc flash venting methods. Should a fault occur, the flash energy is directed through a vent and outside to a safe area. This can be expensive and should only be employed at main substations where the fault currents (and arc flash energy) can be extremely high.

Another interesting way that arc flash energy has been reduced is by the use of flash sensors. The sensors are installed within the switchgear and will trigger if a light flash from a fault (or other source) occurs. These devices then trip the main and tie breakers.



Graph 6 – Solid State Trip Circuit Breaker Time Current Curve

One of least expensive ways to reduce arc flash energy is the modification of work procedures. The best and safest way is to de-energize the equipment and put the equipment into a safe working condition. Although this may seem obvious, it is not always implemented. Before working on energized equipment, the personnel should consider all possible ways to shut the equipment down before working on it. Sometimes this may require working on the equipment during non traditional working hours. But this is definitely the safest method.

However, if de-energizing the electrical equipment is not an option, then consideration should be given to the three items below with the last item being the highest priority.

- Lower the Fault Current
- Increase the Work Distances
- Reduce Device Clearing (Trip) Times

The fault current can sometimes be lowered by the elimination of paralleling of transformers. In many facilities, double ended substations or network faults are paralleled during normal periods. If the equipment is going to be worked on while energized, these paralleled transformers can sometimes be shut down thus lowering the available fault current.

A facility should always eliminate personnel work between a transformer secondary and the downstream secondary (main) breaker when energized. This is the most dangerous (and usually the highest arc flash energy area) location in a distribution system. The arc flash energy is much higher at this location because the primary device is seeing a reduced (when calculated in primary amperes) fault current on the secondary side. This lower fault current seen by the primary device will cause it to trip at a longer delay. This longer delay increases the arc flash energy.

As the discussions stated previously, time is very important when considering arc flash energy calculations. Many modern solid state trip units and protective relays are now employing group settings or maintenance (AFRM) settings. These settings enable the owner to program lower pickups and faster trip times. An external switch is used to instruct the relay or trip unit to use the lower settings. Before work is performed, the electrician simply toggles the switch to the maintenance position. Should a fault occur, the protective device will pick up and trip quickly, and thus reducing the arc flash energy.

Putting distance between the hazard and the electrician is also beneficial. One way to reduce the hazards during infrared surveys is to use infrared windows. These windows are mounted at important locations that need to be inspected by infrared equipment. These windows allow the technician to scan the location to look for hot spots (loose connections) without removing covers and doors.

One of the most hazardous tasks to perform is racking in or out breakers. Many documented accidents have occurred during this operation. Recently, several manufacturers have been marketing remote breaker racking devices. These devices allow the operator to stand to the side while the machine racks in the breaker. Increasing this working distance reduces the arc flash energy at the operator's location.

Summary

We have looked at several ways to reduce the arc flash energy in a facility. Arc flash energy can be reduced by (in order of effect):

- Decreasing the Trip Times
- Reducing Fault Currents
- Increasing the Worker Distance

There are many methods and techniques that the technician or engineer can use to reduce the incident energy levels. Each location should be analyzed by an electrical engineer familiar with incident energy levels to see which solutions are most cost effective and beneficial. Working on the equipment when de-energized is the safest solution and it can be implemented at any location.

About the Presenter

Bob Fuhr graduated with a B.S.E.E. from the University of Wisconsin in 1980. Before graduating, Mr. Fuhr worked for Madison Gas and Electric in Madison, WI and Tennessee Valley Authority in Knoxville, TN.

After graduation, he worked for General Electric Company from 1980 to 1986 as a Field Engineer performing commissioning and start up tests on a multitude of power distribution equipment.

From 1986 to 1989 he worked as a Senior Facilities Engineer at the University of Washington. There he re-commissioned the electrical power distribution system for

University Hospital.

In 1986, he established Power Systems Engineering (now called PowerStudies.com), a consulting firm that specializes in power systems studies, power quality services, and commissioning services. He also teaches classes in electrical safety, short circuit calculation, protective device coordination, arc flash hazard assessment, power factor correction, and harmonics and filter design.

Mr. Fuhr is a Professional Engineer registered in Alaska, Arizona, California, Colorado, New Mexico, Nevada, Oregon, Washington and more.

Bob has been involved in IEEE and the Industrial Applications Society since 1986. He has served as an officer for IAS from 1988 to 1992. He was the 1991-92 Chairperson of IAS. He was a Member-at-large for the Seattle Section of IEEE for 1992-93. He is an IEEE Senior Member. He is also member of the Electric League of the Pacific Northwest.